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Physiological Responses Of Animals To Environmental Stress Conditions

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Abstract
Environmental stressors- including temperature extremes, hypoxia, salinity changes, and chemical pollutants- pose significant challenges to the physiological balance of animals. These stressors disrupt homeostasis and trigger a range of compensatory mechanisms that involve endocrine regulation, metabolic adjustments, oxidative stress responses, and alterations in immune and osmoregulatory function. This review synthesizes current knowledge of the physiological responses of animals to environmental stress, focusing on mechanisms of adaptation, hormonal mediation, oxidative stress pathways, and implications for survival under changing environmental conditions. Understanding these responses is critical to assessing animal resilience, informing conservation strategies, and evaluating ecosystem health in the face of accelerating global change.

Key words: Environmental stressors, Homeostasis, Adaptation

1. Introduction

Any physical or psychological stimuli that disrupt homeostasis result in a stress response. The stimuli are called stressors, and physiological and behavioural changes in response to exposure to stressors constitute the stress response.A stress response is mediated through a complex interplay of nervous, endocrine, and immune mechanisms, activating the sympathetic-adreno-medullar (SAM) axis, the hypothalamic-pituitary-adrenal (HPA) axis, and the immune system (Mifsud and Reul, 2018).The stress response is fundamentally an adaptive mechanism that prepares the body to cope with internal or external challenges. For instance, physiological responses activated during trauma or invasive surgery help limit further tissue damage and promote survival. However, when exposure to a stressor is intense, repeatedly occurs, or persists for a prolonged period, the stress response can become maladaptive and harmful to normal physiological functioning. Chronic activation of stress pathways may lead to adverse outcomes, including depression, anxiety, cognitive dysfunction, and cardiovascular diseases (Ketchesin KD et al. 2017).

Not all stress is inherently harmful. Certain forms of stress are perceived as positive and beneficial, stimulating physiological and psychological processes that promote improved performance. This beneficial stress, termed eustress, enhances energy availability, supports cardiovascular efficiency, improves endurance capacity, and optimizes cognitive functioning, thereby fostering mental alertness and motivation. In contrast, distress represents a maladaptive form of stress that exerts deleterious effects on both physiological and psychological well-being. Stress is categorized into various types viz. Acute stress, Chronic stress, Episodic acute stress, Traumatic stress, Environmental stress, Psychological stress, Physiological stress (Godoy LD. et al, 2018; Swab DF. et al, 2005; Eisen M. et al, 2024; Gu et al. 2024)

The response of animals to stress involves behavioural, metabolic and physiological changes from subcellular to whole animal (Selye, 1936; Collier and Gebremedhin, 2015). The stress response is divided into 2 phases: Acute and Chronic (Friend, 1991). Acute response is driven by autonomic nervous system and chronic response is driven by endocrine system (Bligh, 1976; Bouman and Currie, 1980).

Environmental stress refers to external conditions that disrupt normal physiological functioning in animals. Stressors such as thermal extremes, hypoxia, salinity fluctuations, and pollutants challenge homeostatic equilibrium and force organisms to activate compensatory mechanisms to survive (Ketchesin KD. et al, 2017)). Animals have evolved complex physiological strategies to cope with environmental stress, which involve neuroendocrine regulation, metabolic changes, antioxidant defences, and behaviour modification (Smith AS. Et al, 2013). Given the increasing pace of climate change and anthropogenic disturbance, understanding these responses has become a central focus of ecological and physiological research. (Ecophysiology, 2025)

2. Types of Environmental Stressors

2.1 Thermal Stress

Temperature is a critical determinant of physiological function in animals. Both high and low temperatures can alter enzyme activity, membrane fluidity, and metabolic rates. Cold stress increases thyroxine (T_4)) levels in many vertebrates as part of an adaptive response to increase metabolism and generate body heat (Agustina Cabral, 2012). Thermal stress disrupts homeostasis and is known to increase free radical production and oxidative damage in tissues, leading to changes in metabolic pathways and cellular stress responses (Belhadj Slimen I, 2016; Marcus Vinícius Dias-Souza. et al, 2025). Heat stress significantly increases health complications and mortality rates, particularly in high-producing and heat-sensitive animals (Obeng, J. E., 1985). Reproductive traits of both male and female species are also affected by heat stress (Marai, I. F. M. et al, 2007; Hansen, P. J., 2009).

2.2 Hypoxia

Hypoxia, or low oxygen availability, is common in aquatic environments and high altitudes. Physiological responses include enhanced respiratory activity, metabolic suppression, and upregulation of antioxidant defense systems to mitigate the effects of oxygen limitation and reoxygenation. (Hermes-Lima M and Zenteno-Savín T, 2002)

2.3 Salinity and Osmotic Stress

Aquatic animals are constantly challenged by changes in salinity. Osmoregulatory organs (gills, kidneys) adjust ion transport and water balance to maintain internal equilibrium. Disruption of ionic gradients interferes with cellular function and overall physiological stability. (Tang, CH. et al, 2014)

2.4 Chemical and Pollution Stress

Chemical contaminants such as heavy metals, pesticides, and endocrine disruptors interfere with normal physiology by inducing oxidative stress, damaging tissues, and altering hormonal pathways. These stressors often produce reactive oxygen species (ROS) that exceed the organism's antioxidant capacity. (Shrivastav D et al. 2025)

3. Stress and Homeostasis

Homeostasis refers to the maintenance of internal stability despite external change. Environmental stressors disrupt physiological steady states, forcing animals to initiate adaptive responses aimed at preserving functionality. While short-term stress can be beneficial by priming defense mechanisms, chronic or severe stress can lead to maladaptive responses, physiological exhaustion, and increased susceptibility to disease. (Collier RJ. et al, 2017)

4. Neuroendocrine Regulation of Stress

One of the earliest responses to stress is activation of the hypothalamic–pituitary–adrenal (HPA) axis, which leads to increased secretion of glucocorticoids such as cortisol and corticosterone. These hormones mediate energy redistribution, enhance circulatory and respiratory activities, and help mobilize energy reserves to cope with stress. The sympathetic nervous system also contributes to stress adaptation by increasing catecholamine release. (Mona A. Bakry and Mohamed Hamada, 2025)

5. Metabolic Adjustments

Environmental stress can alter energy metabolism. For example, heat stress reorganizes energy use away from growth and reproduction toward maintaining homeostasis and cellular protection. Under hypoxia, animals may switch from aerobic to anaerobic metabolism, affecting ATP production and increasing metabolic end products. (Belhadj Slimen I, 2016)

6. Oxidative Stress and Antioxidant Defences

A major consequence of many environmental stressors is increased production of reactive oxygen species (ROS), leading to oxidative stress. Animals counteract ROS through a network of antioxidant defenses, including enzymes like superoxide dismutase (SOD), catalase, and glutathione peroxidase. Oxidative stress can impair cellular structures and functions if these defences are overwhelmed. (Shrivastav D. 2025; Puppel K. 2015)

7. Osmoregulation and Ionic Balance

Osmoregulation is essential, especially for aquatic organisms. Changes in environmental salinity disrupt ion transport, which must be corrected to maintain cellular and systemic osmotic balance. Efficient osmoregulatory mechanisms are crucial for animals inhabiting estuarine or variable aquatic environments. (Tang, CH. Et al, 2014)

8. Immune Function and Stress

Physiological stress has complex effects on the immune system. Acute stress may temporarily enhance immune responses, but prolonged stress generally suppresses immunity, making animals more vulnerable to infection and disease. Stress hormones modulate immune cell activities and cytokine production, affecting overall health outcomes. (Engler-Chiurazzi E, 2024; Mona A. Bakry and Mohamed Hamada, 2025). Additionally, chronic stress induces systemic inflammation via the upregulation of inflammatory mediators, thereby playing a significant role in the pathogenesis of autoimmune diseases and chronic inflammatory disorders (Reiche EM et al 2004).

9. Gastrointestinal system response to stress

Catecholamines, including epinephrine and norepinephrine, released during stress exert significant effects on the gastrointestinal system. These hormones act by binding to adrenergic receptors widely distributed throughout the gastrointestinal tract, thereby modulating multiple physiological processes. Specifically, activation of α-adrenergic receptors in intestinal smooth muscle results in delayed gastric emptying and reduced intestinal motility (Bhatia V and Tandon RK, 2005). Moreover, through α-adrenergic receptor–mediated vasoconstriction, blood flow to the gastrointestinal tract is reduced, leading to inhibition of gastrointestinal secretory activity and nutrient absorption (Söderholm JD and Perdue MH, 2001).

10. Musculoskeletal system response to stress

Chronic stress triggers a cascade of physiological responses, including sustained elevation in the secretion of stress hormones such as cortisol and catecholamines, which exert significant effects on the musculoskeletal system. Prolonged exposure to elevated cortisol levels promotes muscle catabolism and reduces bone mineral density by inhibiting osteoblast activity and enhancing osteoclast-mediated bone resorption.In addition, stress-induced activation of the sympathetic nervous system exacerbates musculoskeletal tension and is implicated in the development of tension-type headaches, temporomandibular joint disorders, delayed recovery from musculoskeletal injuries, and an elevated risk of conditions such as fibromyalgia and low back pain(Chu et al. 2024).Stress hormones cause catabolism of muscle proteins, thereby decreasing the muscle strength (Rooyackers Olav E and Nair K Sreekumaran, 1997).Further stress hormones induce oxidative damage in the skeletal muscle and thereby interferes with it quality and function (Li Q. et al, 2011).

11. Cardiovascular system response to stress

Acute stress elicits immediate cardiovascular responses, including increases in heart rate, myocardial contractility, and cardiac output, accompanied by redistribution of blood flow toward the skeletal muscles. In contrast, chronic stress results in sustained activation of the sympathetic nervous system and the hypothalamic–pituitary–adrenal (HPA) axis, leading to persistently elevated circulating levels of stress hormones such as cortisol and epinephrine (Hall M. et al, 2004). The sustained presence of these stress hormones promotes oxidative stress, endothelial dysfunction, and vascular inflammation, thereby facilitating the development of atherosclerosis and impairing vascular function. Furthermore, stress-induced alterations in lipid metabolism contribute to dyslipidemia, which further exacerbates cardiovascular risk (Yaribeygi H. et al., 2017).

12. respiratory system response to stress

Both acute and chronic stress induce bronchial hyperresponsiveness and airway inflammation. Acute stress, in particular, can alter breathing patterns through stress-related airway constriction, resulting in dyspnea and rapid, shallow breathing, thereby exacerbating respiratory symptoms. Chronic stress further compromises immune function, increasing susceptibility to respiratory infections and worsening conditions such as asthma and chronic obstructive pulmonary disease. In addition, stress-induced alterations in inflammatory cytokine profiles contribute to airway inflammation and excessive mucus production (TG Sriram and JJ Silverman, 1998).

13. Integrative and Behavioural Responses

Physiological responses to stress are often coupled with behavioural changes. Animals may modify feeding patterns, seek microhabitats with favourable conditions, or alter reproductive behaviour to improve survival. These integrative responses underscore the connection between physiology and ecology. (Agarwal A. et al, 2005; Ecophysiology, 2025)

14. Ecological and Conservation Implications

Understanding physiological stress responses has important applications in conservation biology. Stress physiology provides biomarkers for assessing the health of populations and their capacity to withstand environmental change. Effective conservation strategies must consider physiological thresholds to mitigate adverse effects on biodiversity and ecosystem resilience. (Ecophysiology, 2025)

15. Conclusion

Animals employ a variety of interconnected physiological mechanisms to cope with environmental stress, including neuroendocrine activation, metabolic rebalancing, antioxidant defences, and adjustments in immune and osmoregulatory function. These coordinated responses enable organisms to maintain homeostasis and survive short-term challenges imposed by environmental stressors such as thermal extremes, hypoxia, nutritional limitation, and anthropogenic disturbances. While such mechanisms provide immediate adaptive benefits, chronic or intense stress can overwhelm regulatory systems, leading to oxidative damage, impaired immune function, reduced reproductive success, and overall declines in health and fitness.

The diversity in stress tolerance observed among species and even among individuals highlights the importance of evolutionary adaptation and physiological plasticity in shaping resilience to environmental change. However, the accelerating pace of climate change and habitat degradation presents unprecedented challenges that may exceed the adaptive capacity of many organisms. Continued research into stress physiology is therefore essential for predicting the biological impacts of environmental change and for developing effective conservation, management, and animal welfare strategies.

In conclusion, integrating physiological, ecological, and molecular perspectives will be crucial for advancing our understanding of animal stress responses and for guiding interventions aimed at safeguarding animal populations and maintaining ecosystem stability in a rapidly changing world.

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